1990

Assessing joint mobility of the lower extremities when walking in water through the use of motion analysis

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Senior Thesis
Presidential Scholars

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03/09/90

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Walking in water is becoming increasingly more popular, both in fitness programs for the general population, and in rehabilitation settings for those with cardiac or musculoskeletal concerns. Physical therapy settings often prescribe walking in the water for patients with lower extremity injuries that limit muscle strength and joint range of motion (ROM) (W. Svoboda, personal communication, August 1989).

The advantages afforded by the properties of water are widely recognized and utilized. First water provides buoyancy or an upward force which counteracts the force of gravity; the degree to which this occurs varies with the level of immersion. This buoyancy reduces the stress placed on the lower extremities by reducing one's weight in the water. For example, when a person is immersed in water up to his neck, his body weight is one-tenth of what it would be out of the water (Edlich, et al. 1987). According to one research grant proposal, field tests to develop an underwater treadmill product yielded an ideal water level of forty inches for water walking (MS Study Research Grant Proposal). This level is said to be optimal because enough weight is relieved with the person still able to maintain stability while exercising.

A second widely hailed advantage of the water is the resistance it offers. Water resists movement to a much greater extent than does air. Therefore similar exercises on land and in water will allow more energy to be expended in the water as well as call for stronger muscle contraction throughout any motion in the water. The properties of buoyancy and resistance account for the benefits that walking in the water offers to those concerned with muscle strengthening and conditioning and to those for whom weight-bearing ability is a factor.

The effect of these properties on ROM has received little attention. Extensive research yielded no previous report of measurement of range of motion when walking in water. Several sources, however, advocate the belief that walking in water does result in increased ROM of the lower extremities based on a variety of reasoning methods. Edlich, et al. (1987) assert that the resistance of the water produces muscular overload with the muscle generating force throughout the range of motion. Thus exercise in water improves muscular extensibility. One should question an assumption used in reaching this conclusion; while muscular strength may be developed throughout the already-existing range of motion for a specific joint, there is no basis for the assertion that ROM will increase.

Another theory that has been used to explain an increase in ROM resulting from the effects of water revolves more around the warmth of the water rather than the properties of the water itself. Lehman, et al (1970) reports that raising the temperature of connective tissue in joints and muscles allows greater elongation of collagenous tissues when stretched. Some researchers have used these studies to conclude that this would result in an increase in ROM (Arthritis study research grant proposal). The temperature that the connective tissue was heated to in this study was 45°C. This temperature is much higher than the conditions presented in this study.

Despite the lack of any attempts to quantify the ROM while walking in water, several products have recently been introduced which utilize the concept of an underwater treadmill to harness the advantages of walking in water, one of which includes an increase in ROM. The purpose of this study is to utilize motion analysis to qualitatively and quantitatively analyze the ROM of the ankle, knee, and hip when walking in the water and to compare these results to those observed when walking on land.

METHODS.

Subjects in this study were four female college students ($\bar{x}$ age =21 years), each within the normal range for height and weight. None of the subjects presented any histories of major lower extremity injury and none displayed any significant gait abnormalities in walking on land.

Videotaping was done with a Panasonic AG 120WG camera for both land and water taping. Subjects were marked with black pen at four landmarks: the base of the fifth toe, just below the lateral malleolus, on the midline of the lateral femoral condyle, and on the tip of the femoral trochanter. In both trials subjects were instructed to walk a distance of about three meters three times each at a normal speed, at a speed slower than normal, and at a speed faster than normal.

The set-up used for the taping of the water walking is depicted in Figure 1. The principle of the half-periscope system used was obtained from J.G. Hay (personal communication, September 12, 1989) and from Hay and Thayer (1989). The water level was approximately 1.1 meters (42 inches) and the water temperature was between 28° C and 29° C. A second mirror perpendicular to the pool surface and just beyond the path of the subject was included in an effort to simultaneously view the sagittal and frontal planes of the subject walking. Due to the confinements of the pool, the frontal view could be obtained for only a fraction of the stride, thus it was omitted from study and research focused on the stride in the sagittal plane.

For the videotaping of walking on land, the trials were conducted on the same walking surface as that in the pool. The walking distance and the distance of the subject from the camera were also approximately equal.

Data were analyzed using the Peak Performance 2D motion measurement system. One trial at each speed for each subject was digitized (12 trials) from the video playback monitor at a frame rate of 60 frames per second for the land walk and 30 fps for the water walk. Peak Performance software and an IBM PC-AT compatible computer was used to process the data, and the filter system was set at 10 Hz.

From this data stride length, stride velocity, and ROM at the hip, knee, and ankle were obtained. Event frames were defined as the following: heel strike (RHS and LHS)= frame in which descending swing leg initiates contact with the ground; toe

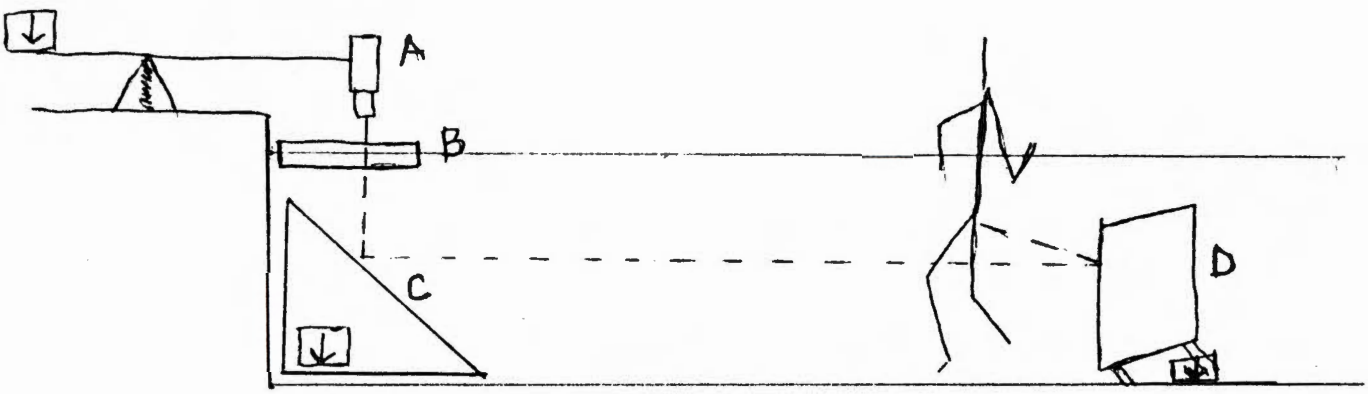


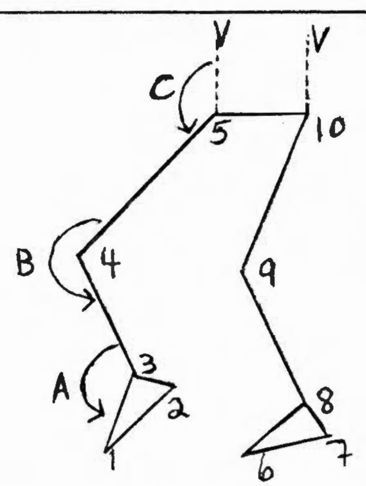
Fig. 1. Schematic representation of modified periscope system used in underwater videotaping. A) Videocamera mounted on anchored board. Actually extends from side of pool. B) Aquarium tied to hand rails and partially immersed in water to serve as a wave breaker. C) Mirror set in frame at 45° angle to pool surface for sagittal viewing. D) Mirror set in frame at 90° angle to pool surface for viewing in the frontal plane.

Fig. 2. (a) Summary of digitized landmarks. (b) Display of landmark numbering assignments with vertical axis indicated and setup for angles used to measure ROM.

(a)

1. base of 5th right toe.
2. right heel.
3. right ankle.
4. right knee.
5. right hip.
6. base of 5th left toe.
7. left heel.
8. left ankle.
9, left knee.
10. left hip.

(b)



A. ankle.
B. knee.
C. hip.

off (RTO and LTO)= frame in which the base of fifth toe of push-off leg loses contact with the ground; midswing (RMS and LMS)= frame in which knee of swing leg begins to extend. Angles are defined in Figure 2. Angles for the hip use the vertical axis as the proximal vector since videotaping below the water's surface did not allow the torso to be viewed.

RESULTS.

ROM values for the left hip, knee, and ankle are presented in Table 1. The left leg was closest to the camera and could be seen throughout the stride. Range of motion was computed for each of these parameters by finding the difference between the minimum and maximum angle attained in the stride. Paired student t tests were performed for each parameter to assess the effect of walking in the water versus on land. These tests indicate that across velocities differences in ROM for the hip and the knee in the water versus on land are significant at the .05 level. For the ankle, no significant differences were found between walking in the water and on land. To illustrate these differences, Figure 3 provides a computer-generated qualitative analysis of the stride in the pool and on land for one subject.

DISCUSSION.

The ROM of the hip and of the knee was significantly greater in the pool than on land. A qualitative analysis supports this finding, as depicted in Figure 3. The minimum angle of the knee usually occurs between midswing and heel strike as the knee

Tab.1. ROM values for each angle of the left side for each trial, including mean ROM and standard deviation (s). Paired student t tests were performed to evaluate differences in ROM when walking in in water and on land. Significance ($p < .05$) is indicated by *.

	Ankle ROM		Knee ROM		Hip ROM	
Trial	POOL	LAND	POOL	LAND	POOL	LAND
1A	55.3	50.8	66.7	65.4	49.4	41.1
1B	48.3	53.4	66.7	65.6	48.0	40.7
1C	68.0	47.3	94.3	63.0	57.6	41.2
2A	43.9	35.8	75.3	63.3	47.7	39.9
2B	31.5	40.3	65.9	64.1	41.8	39.1
2C	38.6	44.3	80.7	62.0	43.8	40.4
3A	56.7	36.5	102.8	61.6	65.0	39.2
3B	53.3	39.0	94.9	62.2	53.9	40.6
3C	59.5	41.6	115.7	63.7	62.1	47.1
4A	51.2	46.0	74.8	61.5	53.4	33.4
4B	45.6	49.6	64.6	58.8	42.9	37.0
4C	51.1	53.8	73.6	63.8	53.8	39.8
$\bar{X}$	50.2	44.9	81.3	62.9	51.6	40.0
s	8.2		11.9		5.7	
t	1.60		3.79*		4.98*	
P	>.05		.025		.010	

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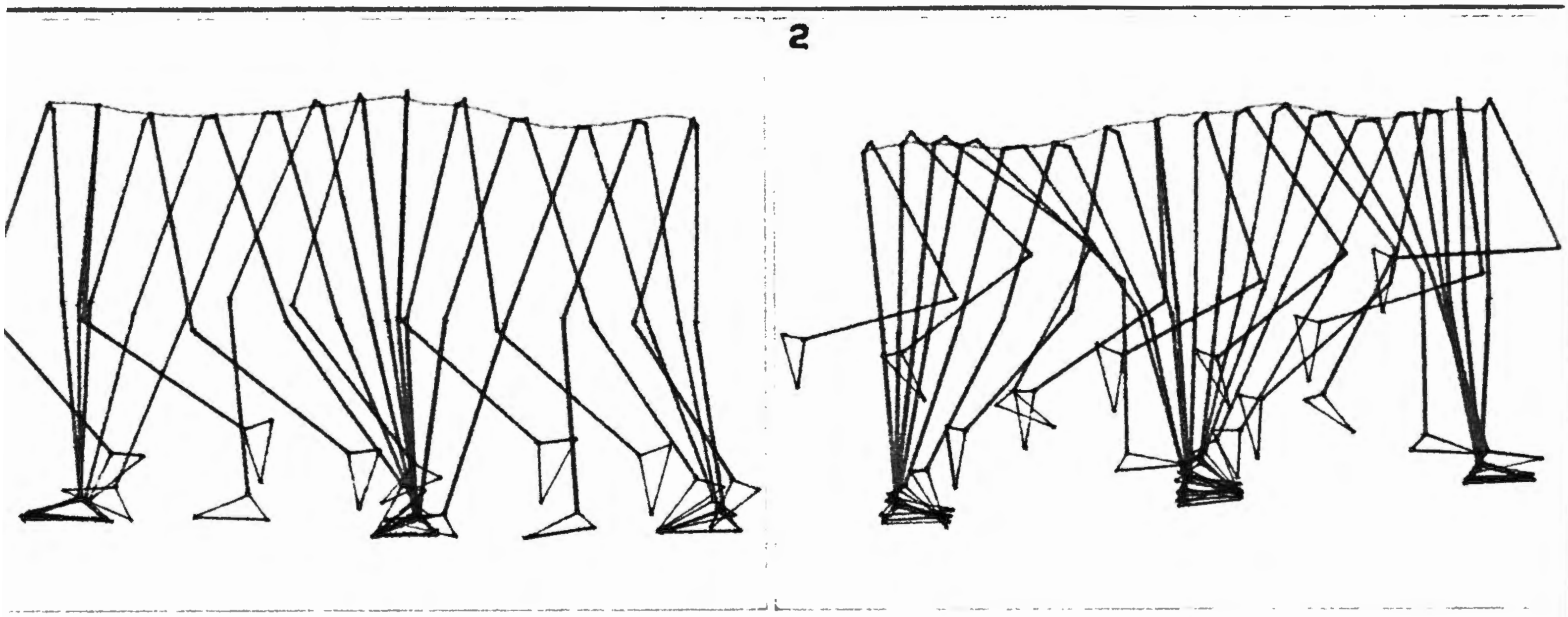
Fig. 2. Computer-generated graphic display of stride for one subject when walking (1) on land and (2) in the water. Time between frames is one-twelfth of a second on land and one-sixth of a second in the water.



extends and reaches outward and downward. The maximum angle of the knee is usually reached at about the time of midswing as the knee is flexed and brought forward over the axis of stability. The minimum angle of the hip is generally attained between midswing and heel strike as the hip flexes to bring the swing leg through. The maximum hip angle occurs between heel strike and toe off as the hip must extend to transfer the body weight to the leading foot.

The part of the stride in which maximum and minimum angles of the ankle were attained reflects less consistency than did the hip and knee. This is probably owing to individual differences and the increased impact of error due to the compact angle components inherent in measuring the ankle's movements.

When walking in the water both the hip and the knee exhibit significantly greater ROM compared to walking on land (Tab. 1). These increases are accounted for at the same portion of the stride, flexion of the swing leg. At about the time of midswing, the hip and knee exhibit greater flexion in the water.

The water resists the motion of bringing the swing leg through, whereas on land the resistance offered by the air is negligible. The force required to overcome this resistance of the water depends on the length of the moment arm as well as the amount of surface area opposing the movement (how streamlined the leg is positioned). Hip and knee flexion are concurrent movements, thus they reinforce each other. This allows one to bring the swing leg through with more force to overcome the resistance of the water. Greater flexion of the hip and knee in the swing phase also decreases the moment arm of the leg by shifting the leg's center of gravity closer to the body. Bringing the leg up higher and tucking the knee in also enhance the ease with which the leg moves through the water as less of the thigh's surface encounters the water's resistance in the forward direction.

In the swing phase of gait, the body weight shifts forward, unbalancing the body and allowing weight to be transferred to the leading foot. In the water, this unbalancing is more difficult to achieve as the force of buoyancy counteracts that of gravity. To overcome this additional stability, the body must compromise by moving the center of gravity further from the base of support. This is accomplished by leaning farther forward and bringing the swing leg up higher (accomplished by increasing hip flexion and, to some extent, increasing knee flexion), thus facilitating the unbalancing needed to complete the transfer of momentum.

CONCLUSIONS.

Motion analysis allows for direct qualitative and quantitative assessment of ROM while walking in water or on land. Not only does this allow for direct measurement of joint angles, it also provides the researcher with a side-by-side comparison of strides from which one may zero in on the portion of the stride where the changes in joint angle occur. Walking in the water does significantly increase the ROM of the hip and the knee in the population studied here. The key phase of the stride in which the significant increase in ROM is noted is the swing phase as the hip and knee attempt to overcome water's properties of resistance and buoyancy.

The results of this study indicate that the use of water walking in rehabilitation settings for the purpose of increasing ROM of the ankle may have to be reconsidered unless additional qualities of the water are present, such as increased water temperature or whirlpool action, although further study is needed to examine the effect of these additional elements on ROM.

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